MODIS

Chlorophyll Fluorescence (MODIS Product Number 20)

Data Quality Summary

26 April 2001

Investigation: **MODIS**

Data Product: **Chlorophyll Fluorescence**

Data Set: **EOS Terra**

Data Set Version: **3**

This page describes the present status of the Chlorophyll Fluorescence products (MOD20) as currently available from the Goddard Distributed Active Archive Center. MOD20 is an entirely new type of data product which has not been collected from space before the launch of EOS Terra. For this reason, quality assessment of the chlorophyll fluorescence products will depend on comparisons with contemporaneous field measurements in a few locations around the world, time series measurements at the MOBY site, and analysis of long time series of MODIS measurements. Therefore it is not possible to assign rigorous error estimates at this time. Instead we will provide consistency checks based on time series analysis and comparisons with other bio-optical properties such as chlorophyll.

Details on the sensor operations, changes in processing algorithms, etc. can be found at the Known Problems and the Product Revisions web pages for MODIS oceans products. Details of band performance can be found on MODIS Calibration Science Team web page. Bands 13 (665.1 nm), 14 (676.7 nm), and 15 (746.3 nm) are used for the fluorescence products. At present, the low gain bands (13L and 14L) are being used. We expect to shift to the high gain bands (13H and 14H) as our understanding and characterization of the sensor improves.

Nature of the MOD20 Product:

The Chlorophyll Fluorescence product consists of three parameters: chlorophyll fluorescence line height (chlor_fluor_ht, parameter 16), chlorophyll fluorescence baseline (chlor_fluor_base, parameter 17), and chlorophyll fluorescence efficiency (chlor_fluor_effic, parameter 18). The primary products are fluorescence line height (hereinafter referred to as FLH) and chlorophyll fluorescence efficiency (hereinafter referred to as CFE). Chlorophyll fluorescence baseline is an intermediate product and is used only in the calculation of FLH. It is not considered further.

The input radiances are the normalized water-leaving radiances from MOD18 by Gordon. These radiances are corrected for sun-sensor geometry as well as for atmospheric scattering and absorption. However, the latter part of this correction (atmospheric effects) is relatively simple compared with the more complex Rayleigh and aerosol corrections required in the blue and blue-green portion of the spectrum. Rayleigh scattering is small at these fluorescence baseline wavelengths, and aerosol scattering does not vary much across this wavelength span (H. Gordon, pers. comm.)

The main component of the MOD20 algorithm is the estimation of the increased radiance caused by chlorophyll fluorescence centered around 683 nm. By defining a baseline underneath the expected fluorescence peak, we estimate the relative contribution to the upwelled radiance field by chlorophyll fluorescence. This baseline is calculated through a linear interpolation between MODIS channels 13 and 15 on either side of the fluorescence peak. The height above this line at 676.7 nm (channel 14) is FLH (W/m^2/μm/sr).

CFE is an estimate of the number of photons emitted through fluorescence relative to the number of photons absorbed (Absorbed Radiation by Phytoplankton, ARP, MOD22, parameter 29). ARP is reported in ein/m^2/s. ARP is calculated such that only chlorophyll from near-surface phytoplankton is considered since FLH is strongly attenuated by water. Thus the ARP and FLH signals are calculated from the same portions of the water column. After accounting for differences in units, CFE is calculated as the ratio of FLH/ARP.

To improve algorithm sensitivity, a 5 by 5 array is centered on each pixel and the FLH calculations are made as the average of valid pixels in this subarray. The 5 by 5 array is then moved over one pixel, and the process is repeated. At the end of the scan line, the array is shifted one line. Thus, the output product consists of FLH and CFE calculated at every pixel, and the number of pixels used to calculate FLH may range from 1 to 25.

Data Accuracies

The chlorophyll fluorescence products primarily depend on the quality of the input radiances in bands 13, 14, and 15. CFE also depends on ARP quality. Validation relies on a three-part approach. The first approach uses systematic studies of large volumes of MODIS observations over several seasons to quantify spatial and temporal error patterns. It also compares the FLH results with other MODIS data products. This will include studies of FLH patterns in the context of geographic and geophysical properties. For example, FLH should be similar to the patterns of chlorophyll; are there systematic differences? How does FLH relate to estimates of aerosol radiance? Are there systematic changes in FLH across a scan line, indicating a dependence on satellite look angle and hence path radiance? Does FLH change near the edges of clouds, where aerosol concentrations may be higher? Are there systematic seasonal changes? The second component of our validation studies is an extension of this approach and will rely on statistical comparisons of MODIS observations with similar measurements from MERIS and GLI after they are launched. The third approach is based on comprehensive

in situ studies, conducted at a few representative sites in the world ocean that span a spectrum of oceanic and atmospheric conditions. MOBY is the foundation of this approach, through its provision of high-quality bio-optical measurements. As an adjunct to MOBY, we are conducting field validation studies off Oregon in both oligotrophic and eutrophic waters. These studies include measurements of bio-optical properties as well as Fast Repetition Rate Fluorometry (FRRF) to estimate photosynthetic potential. Similar measurements have been proposed for the Hawai'i Ocean Time-series site north of Oahu.

The simplest measures of success will be the ability of the algorithms to perform within predicted error limits over a broad range of environmental conditions. A first-order analysis following the initial validation test will be to determine if the algorithms can be applied to different ocean regions or different atmospheric conditions and continue to produce data sets within the expected error. The second measure will be an assessment of the stability of the data products over a long time period. Such analysis may uncover unexplained biases in the long-term record or unexpected seasonal trends.

At this time, we are continuing to work with the University of Miami team on sensor characterization as it affects the chlorophyll fluorescence products. We cannot provide any quantitative error estimates at this time because SeaWiFS does not make equivalent fluorescence measurements. Visual comparisons of FLH with chlorophyll images show that in general the patterns of FLH correspond to those observed in chlorophyll, which is what we would expect. Detectable patterns in FLH are observed in low chlorophyll waters, such as the Gulf Stream. This is consistent with the analysis of Letelier and Abbott (1996) who showed that 5 by 5 averaging should allow retrieval of FLH from waters with chlorophyll levels about 0.1 mg/m^3, depending on the quantum efficiency of fluorescence (Φ_F) and atmospheric turbidity.

Cautions When Using Data

The quality of the chlorophyll fluorescence products depends on the quality of the input variables. Users should be familiar with the nature and performance of these input products. Issues such as mirror side differences, striping caused by variations in detector response, etc. are important for all of the ocean color bands.

The most critical assumption is that atmospheric effects can be removed with a simple model from the three wavelengths used to calculate FLH. MODIS was designed specifically to minimize the impact of atmospheric absorption features on the FLH calculation. This approach also assumes that backscattered sunlight will not pose a significant problem. This may not be the case in waters with heavy particulate loads where backscattering near the ocean surface may be intense. Because particulate materials such as detritus scatter light in the red wavelengths, some of the FLH signal may simply be backscattered sunlight rather than chlorophyll fluorescence. Moreover, errors in the bands may lead to an incorrect estimate of the fluorescence baseline which in turn would affect FLH.

Both CFE and FLH will be calculated only for non-cloud, glint-free ocean pixels during daylight hours. The fluorescence bands tend to saturate at lower radiances than the other ocean color bands so cloud and glint masks may not be sufficiently conservative. Caution should be used in vicinity of clouds and sun glint.

Because FLH is not a strict function of chlorophyll due to variations in Φ_F, estimating chlorophyll concentration from FLH should be done with caution. However, in turbid waters or waters with significant CDOM, FLH might be a useful indicator of chlorophyll. Ratios of FLH to chlorophyll may also be good indicators of photosynthetic capacity. Comparisons of FRRF-derived measurements of photosynthetic capacity showed interesting correlations with FLH/chlorophyll off the Oregon coast (Abbott et al., 2000). However, a simple relationship between the two should not be expected. This remains an area of active research.

Validation Study Results

As noted earlier, validation of the MOD20 chlorophyll fluorescence products is continuing as we understand the basic characterization of the sensor. Much of the validation depends on analysis of long time series. We expect initial results to appear after we have one complete seasonal cycle of stable, well-characterized chlorophyll fluorescence products.

Quality Assurances

We calculate several quality flags in the following manner which is being updated from the present approach as documented on the MODIS Oceans Quality Assurance web page. In the product-specific flag which include the fluorescence products, we set flags to "1" as follows:

Bit 6 FLH/chlorophyll > 1 (use MOD19, parameter 14, chlor_MODIS)

Bit 7 FLH/chlorophyll > 0.5

Bit 8 FLH > 2

Bit 9 FLH > 1

Bit 10 chlorophyll = -1

Bit 11 ARP quality $\geqq$ 2

Bit 12 ARP quality = 1

Bit 13 CFE > 0.1

Common flags will be based tests performed for all of the MODIS Oceans data products. These flags will be:

> Product input-specific (bands 13, 14, and 15 for chlorophyll fluorescence) normalized water-leaving radiances ($[L_w]n$) are negative (saturated or unsaturated)

> Glint

Cloudy (percent albedo at 865 > .9)

Land

Unprocessed (bad geolocation)

Atmospheric correction failed

Quality levels would be set as follows where 0 is best and 3 is worst. The quality levels are determined from various combinations of the flags. For FLH, quality levels are as follows:

Set to 0 if common flags are clear and bits 6-10 are clear

Set to 1 if bits 7 or 9 are set but 6, 8, and 10 are clear

Set to 2 if bits 6, 8, or 10 are set

Set to 3 if any common flags are set

For CFE, quality levels are as follows:

Set to 0 if common flags are clear and bits 11 and 12 are clear

Set to 1 if bit 12 is set or if FLH quality equals 1

Set to 2 if bit 11 or bit 13 is set or if FLH quality equals 2

Set to 3 if any common flags are set or if CFE > 0.15 or if FLH quality equals 3

If any of the following are true then increment quality level by one (make it worse):

Bad ancillary data (ozone, humidity, pressure, etc.)

Solar zenith angle > 70.0°

Satellite zenith angle > 55.0°

We remind the user that the present flag descriptions can be found at MODIS Oceans Quality Assurance. The above discussion pertains only to the new flags and the MODIS Oceans Quality Assurance will be updated to reflect these changes.

Web Links to Relevant information

MODIS Oceans Team

MODIS Oceans Quality Assurance

Expected Reprocessing

The MODIS Oceans products will begin to be reprocessed in summer 2001 to reflect changes in our understanding of sensor performance as well as to correct coding errors. Data created before this reprocessing should be used with caution.

We are exploring a new approach to the calculation of FLH with Howard Gordon. This will perform a rigorous atmospheric correction, rather than rely on the fluorescence baseline. The algorithm is similar to the approach being taken for the next-generation coccolith calculation. Atmospheric correction is based on our knowledge of the

absorption properties of water at 667, 748, and 869 nm as well as backscattering at 550 nm. By comparing the measured radiances with those estimated from theory (in the absence of fluorescence), we can estimate FLH in reflectance units.

Referencing Data in Journal Articles

An error and sensitivity analysis for the MODIS fluorescence products can be found in:

Letelier, R.M., and M.R. Abbott, An analysis of chlorophyll fluorescence algorithms for the Moderate Resolution Imaging Spectrometer (MODIS), Rem. Sensing Environ., 58, 215-223, 1996.

Abbott, M.R., Letelier, R.M., Laney, S., and Bartlett, J.S., 2000, Field and laboratory measurements of passive fluorescence and applications to MODIS data: in Proceedings of SPIE (Ocean Optics XV) CD-ROM. Palos Verdes Estates, CA: SPIE.